# Appendix A

# Fate and Transport Results

# Appendix A

# Fate and Transport Results

## A.1 DEVELOPMENT OF ICDF LANDFILL WASTE ACCEPTANCE CRITERIA CONCENTRATION SPREADSHEET

The methodology for determining the allowable Tier 1 Waste Acceptance Criteria (WAC) concentrations for each constituent is presented in Figure 1. The focus of this discussion is the development of the remedial action objective (RAO) risk-based criteria (RBC) concentrations ($C_{RBC}$) identified by the box above the Tier 1 line. The methodology specific to the $C_{RBC}$ is graphically presented in Figure 2. The spreadsheet is included as Table A-1, following this text.

The following discussion focuses on the $C_{RBC}$ determination. The remaining criteria were not included in the 60% spreadsheet.

### A.1.1 Step 1: Identify the ICDF Design Constituents and Concentrations

The design constituents are defined in the *INEEL CERCLA Disposal Facility Design Inventory*. The anticipated overall concentrations for disposal at the ICDF are determined based on the information contained in the design inventory. These concentrations were calculated and provided by BBWI.

## A.2 CARCINOGENIC RISK CRITERIA

### A.2.1 Step 2: Determine $C_{RBC\ 1}$ in soil based on an equally apportioned cumulative carcinogenic risk in groundwater of 1E-4

The $C_{RBC\ 1}$ is a soil-based concentration initially determined based on equally apportioning the risk to all constituents that pose a carcinogenic risk. As stated in the ROD, this RAO is defined as a risk from groundwater. As such, the calculated groundwater concentrations must be back calculated to an equated soil-based concentration.

The groundwater carcinogenic risks are calculated using the *Risk Assessment Guidance for Superfund: Volume 1 Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)* (EPA, 1991). It is assumed that the available risk (i.e., 1E-4) is equally distributed among all the carcinogenic contributing constituents. The calculated groundwater concentrations are defined as the $C_{RBC\ GW}$.

The soil concentrations were calculated by taking the $C_{RBC\ GW}$ values for each constituent divided by the dilution attenuation factor (DAF) and then divided by a decay factor related to the half-life for each element, and decayed to the modeled peak concentration time in the aquifer. If the formula for the decay factor was reporting 0, 1E-99 was entered for the decay factor. If the constituent does not decay, such as some inorganics, a 1 was entered for the decay factor. These $C_{RBC\ 1}$ soil concentrations represent the concentration of the constituent that would pose a cumulative risk of 1E-4. Equation (1) is presented below. Additional discussion supporting the DAF and Decay calculations is provided as follows.

$$C_{RBC\ 1} = C_{RBC\ GW} / (DAF * decay) \quad (1)$$

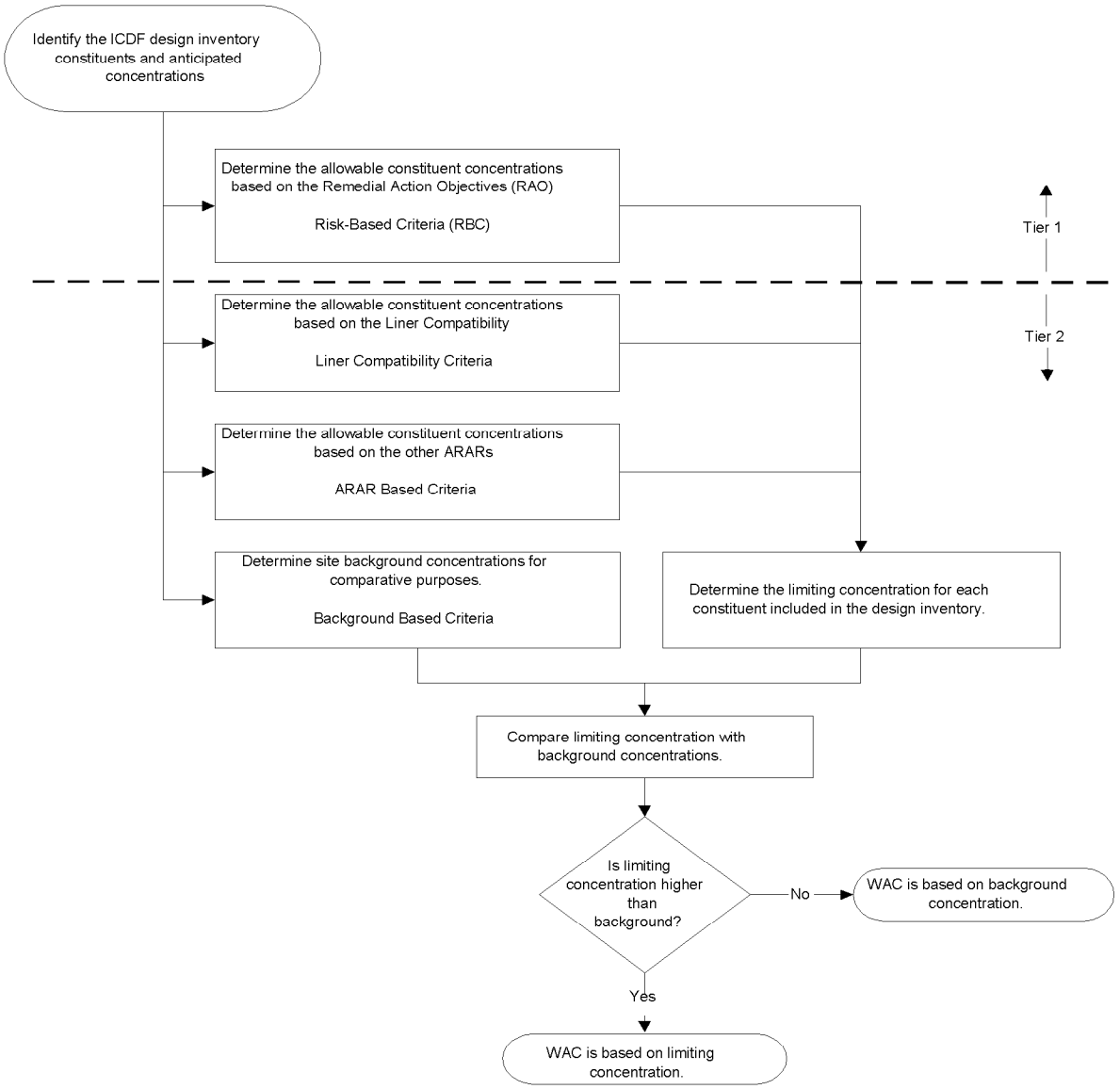


**Figure A-1.** Landfill WAC for Tier 1 and Tier 2 Evaluations (60% design).

### A.2.1.1 Dilution/Attenuation Factor, DAF

The DAF (the peak concentration for the constituent) was determined for the constituents based on the modeling for the following radionuclides: H-3, I-129, Tc-99, U-235, Np-237, Sr-90, Zn-65, and Eu-155. This modeling is discussed in the "Fate and Transport Report, Modeling Results and Summary Report" (DOE-ID 2001f). The calculated DAF for these constituents was also applied to the other constituents (both radiological and non-radiological), based on similarity of $K_d$ values. For the organic constituents, the $K_{oc}$ (organic carbon partition) coefficient was identified when it was available. This was multiplied by the fraction of organic carbon in the soil to determine the $K_d$ (distribution coefficient) values for the organic constituents.

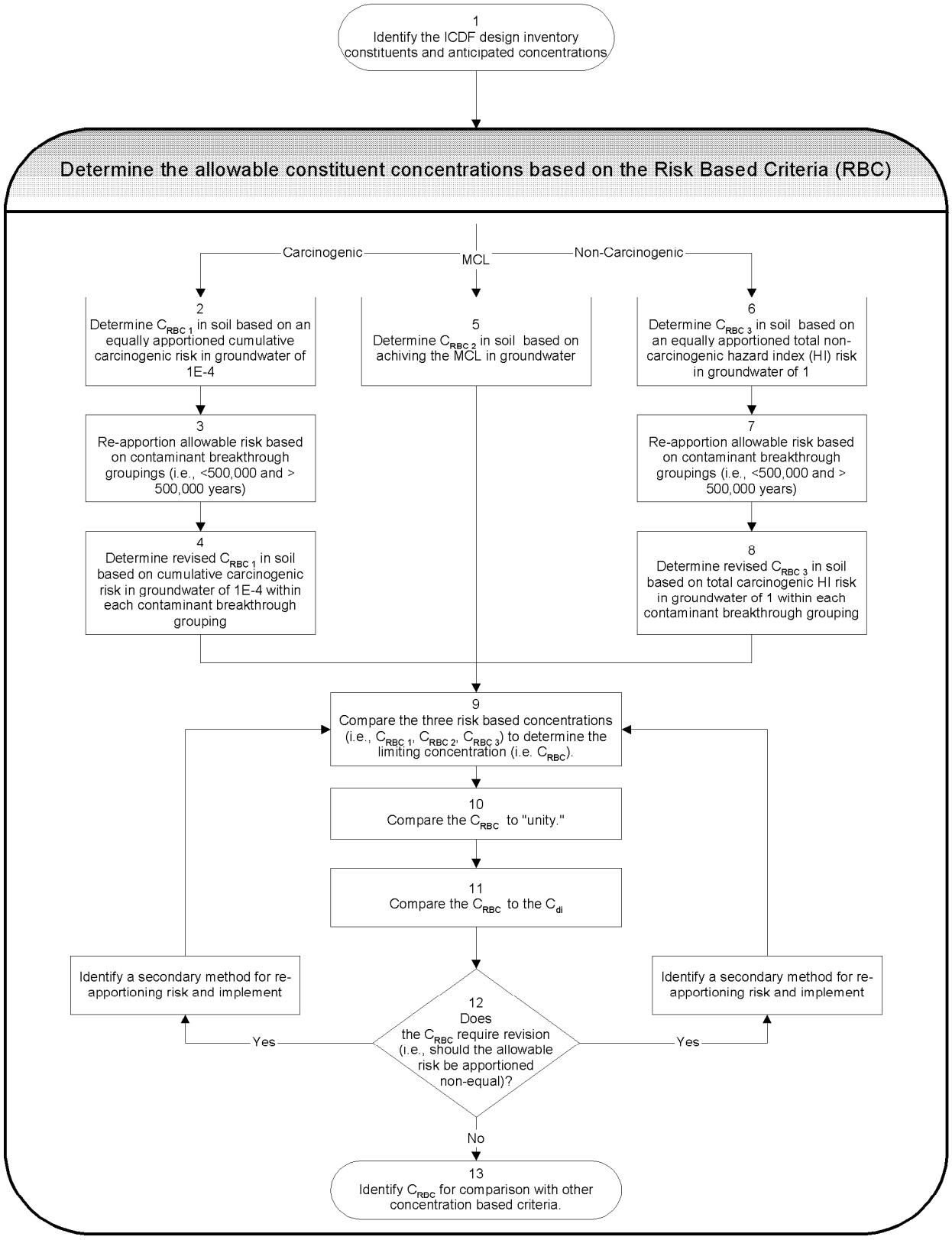


**Figure 2.** Development of Risk Based Criteria Logic.

The weighted average vadose zone $K_d$ is used to group constituents with similar anticipated travel times through the vadose zone. The weighted average vadose zone $K_d$ was selected as an indicator of the relative mobility of specific contaminants in the vadose zone beneath the ICDF. The weighted average $K_d$ was computed by multiplying the fractional vadose zone thickness of each stratigraphic unit by the contaminant-specific $K_d$ for each unit and summing the result. Equation (2) is presented below.

$$K_d = (K_d * 0.077)_{waste\ soils} + (K_d * 0.019)_{clean\ alluvium} + (K_d * 0.006)_{clay\ materials} + (K_d * 0.162)_{interbeds\ materials} + (K_d * 0.736)_{vadose\ zone\ basalt} \quad (2)$$

- The fraction of organic carbon in the layers of soil is from personal communication between Chuck Miller and Marty Doornbos from INEEL.

- "Waste Soils $K_d$ (mL/g)"—For the organic constituents, this column equals the Organic Carbon Partition Coefficient times 0.0025. The $K_d$s for radionuclides are from a letter from Talley Jenkins dated July 3, 2001.

- "Clean Alluvium $K_d$ (mL/g)"—For the organic constituents, this column equals the Organic Carbon Partition Coefficient times 0.0025. The $K_d$s for radionuclides are from a letter from Talley Jenkins dated July 3, 2001.

- "Clay Materials $K_d$ (mL/g)"—For the organic constituents, this column equals 0. The $K_d$s for radionuclides are from a letter from Talley Jenkins dated July 3, 2001.

- "Interbeds Materials $K_d$ (mL/g)"—For the organic constituents, this column equals the Organic Carbon Partition Coefficient times 0.0005. The $K_d$s for radionuclides are from a letter from Talley Jenkins dated July 3, 2001.

- "Vadose Zone Basalt $K_d$ (mL/g)"—For the organic constituents, this column equals the Organic Carbon Partition Coefficient times 0. The $K_d$s for radionuclides are from a letter from Talley Jenkins dated July 3, 2001.

- "Vadose Zone Weighted Average $K_d$"—This column is a thickness-weighted average of columns G through K. The column equals (Waste Soils $K_d$ *0.077)+(Clean Alluvium $K_d$ *0.019)+(Clay Materials $K_d$ *0.006)+(Interbeds Materials $K_d$ *0.162)+(Vadose Zone Basalt $K_d$ *0.736). The weighted average vadose zone $K_d$ is used to group constituents with similar anticipated travel times through the vadose zone. The weighted average vadose zone $K_d$ was selected as an indicator of the relative mobility of specific contaminants in the vadose zone beneath the ICDF. The weighted average $K_d$ was computed by multiplying the fractional vadose zone thickness of each stratigraphic unit by the contaminant-specific $K_d$ for each unit and summing the results.

### A.2.1.2 Decay Constant, $e^{-\lambda t}$

Similar to the DAF, the decay constant was determined based on the peak arrival time for the constituents (in years) based on modeling for the following radionuclides: H-3, I-129, Tc-99, U-235, Np-237, Sr-90, Zn-65, and Eu-155. This modeling is discussed in the "Fate and Transport Report, Modeling Results and Summary Report" (DOE-ID 2001). The calculated peak time (t) for these constituents was also applied to the other constituents (both radiological and non-radiological), based on similarity of $K_d$ values.

- The "Simulated Long Term Groundwater Contaminant Concentration Peak Arrival Time (yrs)" is a result from the STOMP simulation. This is the time that it will take for a constituent in the waste soil in the landfill to reach a peak concentration in groundwater at the point of compliance.

### A.2.2 Step 3: Re-apportion allowable risk based on contaminant breakthrough groupings (i.e., <500,000 and > 500,000 years)

Selected DI constituents (i.e., H-3, I-129, Tc-99, U-235, Np-237, Sr-90, Zn-65, Eu-155) were modeled to determine the anticipated peak time for contaminant breakthrough. The contaminant breakthrough time was plotted against the concentration to determine if there was an apparent grouping of contaminants. The modeling and associated graph is discussed in the Fate and Transport Report (DOE-ID 2001f). Based on these efforts, it was determined that there were two apparent groups of contaminants. The first group impacted groundwater through the first 500,000 years with the remaining group impacting groundwater during the final 500,000 years. The constituent $K_d$ is used to compare and match the remaining constituents as this modeling was accomplished for only a select number of constituents.

The first group of constituents had 33 carcinogenic constituents and 75 non-carcinogenic constituents. The second group had 177 carcinogenic constituents and 35 non-carcinogenic constituents. Constituents can have both carcinogenic and non-carcinogenic effects; however, the radionuclides were assumed to only have carcinogenic effects. Some constituents don't have carcinogenic or non-carcinogenic RBCs because this information was unavailable.

The modeling effort provided a basis for re-apportioning the allowable risk based on this contaminant grouping. The risk was equally re-apportioned such that each contaminant grouping met the cumulative value. Equation (3) provided the re-apportioned risk allocated to each constituent.

$$(1E\text{-}4 - \Sigma R_{RBC\,1}) / (\textit{constituent number in group}) = \textit{constituent re-apportioned risk allocation} \quad (3)$$

Example: The equally apportioned risk allocated to each constituent within the DI is equivalent to 4.74E-7. Following the constituent grouping based on breakthrough; each constituent within the first group can have an additional individual risk of 2.47E-6.

- "Fractional Carcinogenic Risk at Preliminary RBC"—This column is equal to 10-4 divided by the sum of all the carcinogenic constituents in both time groups (less than 500,000 years and greater than 500,000 years).

- "Available Carcinogenic Risk to be Added (Redistributed) to Preliminary Risk"—This column equals 1E-4 minus the quantity (the number of carcinogenic constituents for the time group times the carcinogenic risk at RBC). This value is then divided by the number of carcinogenic constituents for the time group. This is the amount of available carcinogenic risk to add to the previous level of risk. This can be done because each time group is allowed to have a cumulative risk of 10-4.

- "Adjusted Fractional Carcinogenic Risk"—This column is the new, apportioned risk. The column equals the Fractional Carcinogenic risk at Preliminary RBC plus the available carcinogenic risk to be added (redistributed) to Preliminary risk.

- "Adjusted Carcinogenic RBC-based Waste Soil Concentration (Ci/kg or mg/kg)"—This is the waste soil concentration that correlates with the adjusted carcinogenic risk. This column equals

Adjusted Fractional carcinogenic risk times Carcinogenic RBC-based Waste Soil Concentration (Ci/kg or mg/kg) divided by Fractional Carcinogenic risk at Preliminary RBC.

## A2.3 Step 4: Determine revised $C_{RBC\ 1}$ in soil based on cumulative carcinogenic risk in groundwater of 1E-4 within each contaminant breakthrough grouping

It is assumed that the constituent concentrations and associated risks are linear. As such, the re-apportioned individual constituent risk can easily be used to determine an associated concentration. This adjusted $C_{RBC\ 1}$ is determined based on the following equation (4):

$$Adjusted\ C_{RBC\ 1} = (R_{RBC\ 1} / R_{RBC}) * C_{RBC\ 1} \quad (4)$$

## A.2.4 Step 5: Determine $C_{RBC\ 2}$ in soil based on achieving the MCL in groundwater

The maximum contaminant levels (MCLs) are from the National Primary Drinking Water Regulations Table (EPA 2001). This MCL is converted to a soil concentration as described in Step 2 above.

## A.2.5 Step 6: Determine $C_{RBC\ 3}$ in soil based on an equally apportioned total non-carcinogenic hazard index (HI) risk in groundwater of 1

The methodology and implementation discussed in step 2 is similarly applied to the non-carcinogenic HI.

- "The Non-carcinogenic HI = 1 Preliminary RBC (mg/L)"—This value is the concentration for each constituent that correlates with an HI of 1 in groundwater divided by the total number of non-carcinogenic constituents.

- "The $C_{RBC\ 3}$ Non-carcinogenic RBC-based Waste Soil Concentration (mg/kg)"—This is the Non-carcinogenic RBC-based concentration in waste soil.

## A.2.5 Step 7: Re-apportion allowable risk based on contaminant breakthrough groupings (i.e., < 500,000 and > 500,000 years)

The methodology and implementation discussed in step 3 is similarly applied to the non-carcinogenic HI.

- "Non-Carcinogenic Hazard Index at Preliminary RBC"—This column is equal to 1 divided by the sum of all the non-carcinogenic constituents in both time groups (less than 500,000 years and greater than 500,000 years).

- "Available Non-carcinogenic Fractional Hazard Index to be Added (Redistributed) to Preliminary Hazard Index"—This column equals 1 minus the quantity (the number of non-carcinogenic constituents for the time group times the non-carcinogenic risk at RBC). This value is

then divided by the number of non-carcinogenic constituents for the time group. This is the amount of available non-carcinogenic hazard index to add to the previous level of hazard index. This can be done because each time group is allowed to have a cumulative hazard index of 1.

- "Adjusted Non-carcinogenic Fractional Hazard Index" This column is the new, apportioned hazard index"—The column equals Non-Carcinogenic Hazard Index at Preliminary RBC plus the Available Non-carcinogenic Fractional Hazard Index to be Added (Redistributed) to Preliminary Hazard Index.

- "Adjusted Non-Carcinogenic RBC-based Waste Soil Concentration (mg/kg)"—This is the waste soil concentration that correlates with the adjusted non-carcinogenic hazard index. This column equals Adjusted non-carcinogenic fractional hazard index times Non-Carcinogenic RBC-based Waste Soil Concentration (mg/kg) divided by Non-Carcinogenic Hazard Index at Preliminary RBC.

### A.2.6 Step 8: Determine revised $C_{RBC\ 2}$ in soil based on total non-carcinogenic HI risk in groundwater of 1 within each contaminant breakthrough grouping

It is assumed that the constituent concentrations and associated risks are linear. As such, the re-apportioned individual constituent risk can easily be used to determine an associated concentration. This adjusted $C_{RBC\ 3}$ is determined based on the following equation (5):

$$Adjusted\ C_{RBC\ 3} = (R_{RBC\ 3} / R_{RBC}) * C_{RBC\ 3} \quad (5)$$

### A.2.7 Step 9: Compare the three risk based concentrations (i.e., $C_{RBC\ 1}$, $C_{RBC\ 2}$, and $C_{RBC\ 3}$) to determine the limiting concentration (i.e., $C_{RBC}$)

Each $C_{RBC\ X}$ is compared against the others to determine the limiting (minimum) concentration. This evaluation provides the basis for selecting the soil-based concentration that achieves the RAOs.

- The screening of the carcinogenic, non-carcinogenic, and MCL-based waste soil concentrations is performed. This column returns "NA" if the carcinogenic RBC-based waste soil concentration, non-carcinogenic RBC-based waste soil concentration and MCL-based waste soil concentration are all "NA". Otherwise, it takes the smallest of the three.

### A.2.8 Step 10: Compare the $C_{RBC}$ to "unity"

The $C_{RBC}$ that was selected in step 9 is compared against "unity" ($10^6$ mg/kg). For radionuclides, the specific activity is used to convert the Ci/kg to mg/kg. All $C_{RBC}$s that were greater than $10^6$ mg/kg were replaced with a "No Limit." This eliminated concentrations that are not physically possible (greater concentration than pure).

### A.2.9 Step 11: Compare the $C_{RBC}$ to the $C_{DI}$

The $C_{RBC}$ was compared to the $C_{DI}$ to determine if additional risk apportioning should be accomplished. Re-apportioning may be necessary if $C_{DI} > C_{RBC}$.

- A "Yes" is returned if the design inventory is greater than the selected waste soil concentration.

## A.2.10 Step 12: Does the $C_{RBC}$ require revision (i.e., should the allowable risk be apportioned non-equally)?

Based on the comparison accomplished in Step 11, it was determined that additional risk apportioning was not necessary. Minimal constituents $C_{DI}$ exceeded the $C_{RBC}$. These constituents are 2-nitroaniline, 3-nitroaniline, 4-nitroaniline, arsenic, boron, cyanide, vanadium, barium and manganese. These constituents are anticipated to be addressed through the evaluation of background concentrations and by anticipated modifications in the design inventory.

- An evaluation is performed of the design inventory in comparison to the CRBC. A "Yes" is returned if the design inventory is greater than the selected waste soil concentration.